

Electrochemical DNA sensor based on carbon black—poly(Neutral red) composite for detection of oxidative DNA damage

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Abstract

© 2018 by the authors. Licensee MDPI, Basel, Switzerland. Voltammetric DNA sensor has been proposed on the platform of glassy carbon electrode covered with carbon black with adsorbed pillar[5]arene molecules. Electropolymerization of Neutral Red performed in the presence of native or oxidatively damaged DNA resulted in formation of hybrid material which activity depended on the DNA conditions. The assembling of the surface layer was confirmed by scanning electron microscopy and electrochemical impedance spectroscopy. The influence of DNA and pillar[5]arene on redox activity of polymeric dye was investigated and a significant increase of the peak currents was found for DNA damaged by reactive oxygen species generated by Cu²⁺/H₂O₂ mixture. Pillar[5]arene improves the electron exchange conditions and increases the response and its reproducibility. The applicability of the DNA sensor developed was shown on the example of ascorbic acid as antioxidant. It decreases the current in the concentration range from 1.0 μM to 1.0 mM. The possibility to detect antioxidant activity was qualitatively confirmed by testing tea infusion. The DNA sensor developed can find application in testing of carcinogenic species and searching for new antitumor drugs.

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Keywords

DNA sensor, Electrochemical impedance spectroscopy, Electropolymerization, Oxidative DNA damage, Poly(neutral red)

References

- [1] Bai, H.; Wang, R.; Hargis, B.; Lu, H.; Li, Y. A SPR aptasensor for detection of avian influenza virus H5N1. *Sensors* 2012, 12, 12506–12518. [CrossRef] [PubMed]
- [2] Yao, F.; Zhang, Y.; Wei, Y.; Kang, X. A rapid and sensitive detection of HBV DNA using a nanopore sensor. *Chem. Commun.* 2014, 50, 13853–13856. [CrossRef] [PubMed]
- [3] Singhal, C.; Pundir, C.S.; Narang, J. A genosensor for detection of consensus DNA sequence of dengue virus using ZnO/Pt-Pd nanocomposites. *Biosens. Bioelectron.* 2017, 97, 75–82. [CrossRef] [PubMed]
- [4] Ghosh, S.; Datta, D.; Cheema, M.; Dutta, M.; Strosio, M.A. Aptasensor based optical detection of glycosylated albumin for diabetes mellitus diagnosis. *Nanotechnology* 2017, 28. [CrossRef] [PubMed]
- [5] Topkaya, S.N.; Ozkan-Ariksoysal, D.; Kosova, B.; Ozel, R.; Ozsoz, M. Electrochemical DNA biosensor for detecting cancer biomarker related to glutathione S-transferase P1 (GSTP1) hypermethylation in real samples. *Biosens. Bioelectron.* 2012, 31, 516–522. [CrossRef] [PubMed]

- [6] Jo, H.; Gu, H.; Jeon, W.; Youn, H.; Her, J.; Kim, S.-K.; Lee, J.; Shin, J.H.; Ban, C. Electrochemical aptasensor of cardiac troponin I for the early diagnosis of acute myocardial infarction. *Anal. Chem.* 2015, 87, 9869-9875. [CrossRef] [PubMed]
- [7] Eksin, E.; Muti, M.; Erdem, A. Chitosan/ionic liquid composite electrode for electrochemical monitoring of the surface-confined interaction between mitomycin C and DNA. *Electroanalysis* 2013, 25, 2321-2329. [CrossRef]
- [8] Zhao, D.; Li, J.; Yang, T.; He, Z. "Turn off-on" fluorescent sensor for platinum drugs-DNA interactions based on quantum dots. *Biosens. Bioelectron.* 2014, 52, 29-35. [CrossRef] [PubMed]
- [9] Altay, C.; Eksin, E.; Congur, G.; Erdem, A. Electrochemical monitoring of the interaction between temozolamide and nucleic acids by using disposable pencil graphite electrodes. *Talanta* 2015, 144, 809-815. [CrossRef] [PubMed]
- [10] Pokhrel, L.R.; Ettore, N.; Jacobs, Z.L.; Zarr, A.; Weir, M.H.; Scheuerman, P.R.; Kanel, S.R.; Dubey, B. Novel carbon nanotube (CNT)-based ultrasensitive sensors for trace mercury(II) detection in water: A review. *Sci. Total Environ.* 2017, 574, 1379-1388. [CrossRef] [PubMed]
- [11] Sett, A.; Das, S.; Bora, U. Functional nucleic-acid-based sensors for environmental monitoring. *Appl. Biochem. Biotechnol.* 2014, 174, 1073-1091. [CrossRef] [PubMed]
- [12] Song, B.; Shen, M.; Jiang, D.; Malla, S.; Mosa, I.M.; Choudhary, D.; Rusling, J.F. Microfluidic array for simultaneous detection of DNA oxidation and DNA-adduct damage. *Analyst* 2016, 141, 5722-5729. [CrossRef] [PubMed]
- [13] Guo, Z.; Liu, X.; Liu, Y.; Wu, G.; Lu, X. Constructing a novel 8-hydroxy-2-deoxyguanosine electrochemical sensor and application in evaluating the oxidative damages of DNA and guanine. *Biosens. Bioelectron.* 2016, 86, 671-676. [CrossRef] [PubMed]
- [14] Berghian-Grosan, C.; Radu Biris, A.; Coros, M.; Pogacean, F.; Pruneanu, S. Electrochemical and spectroscopic studies of ssDNA damage induced by hydrogen peroxide using graphene based nanomaterials. *Talanta* 2015, 138, 209-217. [CrossRef] [PubMed]
- [15] Ding, J.; Qin, W. Potentiometric sensing of nuclease activities and oxidative damage of single-stranded DNA using a polycation-sensitive membrane electrode. *Biosens. Bioelectron.* 2013, 47, 559-565. [CrossRef] [PubMed]
- [16] Turrens, J.F. Mitochondrial formation of reactive oxygen species. *J. Physiol.* 2003, 552, 335-344. [CrossRef] [PubMed]
- [17] Sies, H. Oxidative stress: Oxidants and antioxidants. *Exp. Physiol.* 1997, 82, 291-295. [CrossRef] [PubMed]
- [18] Abe, F.R.; Gravato, C.; Soares, A.M.V.M.; de Oliveira, D.P. Biochemical approaches to assess oxidative stress induced by exposure to natural and synthetic dyes in early life stages in zebrafish. *J. Toxicol. Environ. Health A* 2017, 80, 1259-1268. [CrossRef] [PubMed]
- [19] Shimura, T.; Sasatani, M.; Kawai, H.; Kamiya, K.; Kobayashi, J.; Komatsu, K.; Kunugita, N. ATM-mediated mitochondrial damage response triggered by nuclear DNA damage in normal human lung fibroblasts. *Cell Cycle* 2017, 16, 2345-2354. [CrossRef] [PubMed]
- [20] Breen, A.P.; Murphy, J.A. Reactions of oxyl radicals with DNA. *Free Radic. Biol. Med.* 1995, 18, 1033-1077. [CrossRef]
- [21] Machini, W.B.S.; Oliveira-Brett, A.M. Antileishmanial drug miltefosine-dsDNA interaction in situ evaluation with a DNA-electrochemical biosensor. *Electroanalysis* 2018, 30, 48-56. [CrossRef]
- [22] Bernalte, E.; Carroll, M.; Banks, C.E. New electrochemical approach for the measurement of oxidative DNA damage: Voltammetric determination of 8-oxoguanine at screen-printed graphite electrodes. *Sens. Actuators B* 2017, 247, 896-902. [CrossRef]
- [23] Zhang, Q.; Dai, P.; Yang, Z. Sensitive DNA-hybridization biosensors based on gold nanoparticles for testing DNA damage by Cd(II) ions. *Microchim. Acta* 2011, 173, 347-352. [CrossRef]
- [24] Gai, Q.-Q.; Wang, D.-M.; Huang, R.-F.; Liang, X.-X.; Wu, H.-L.; Tao, X.-Y. Distance-dependent quenching and enhancing of electrochemiluminescence from tris(2,2-bipyridine) ruthenium (II)/tripropylamine system by gold nanoparticles and its sensing applications. *Biosens. Bioelectron.* 2018, 118, 80-87. [CrossRef] [PubMed]
- [25] Sani, N.D.M.; Heng, L.Y.; Marugan, R.S.P.M.; Rajab, N.F. Electrochemical DNA biosensor for potential carcinogen detection in food sample. *Food Chem.* 2018, 269, 503-510. [CrossRef] [PubMed]
- [26] Ajmal, M. Electrochemical studies on some metal complexes having anti-cancer activities. *J. Coord. Chem.* 2017, 70, 2551-2588. [CrossRef]
- [27] Zhang, W.; Yang, T.; Li, W.; Li, G.; Jiao, K. Rapid and sensitive electrochemical sensing of DNA damage induced by VO nanobelts/HCl/HO system in natural dsDNA layer-by-layer films. *Biosens. Bioelectron.* 2010, 25, 2370-2374. [CrossRef] [PubMed]
- [28] Zhang, W.; Yang, T.; Yin, C.; Li, G.; Jiao, K. An enhanced strategy using poly(m-aminobenzene sulfonic acid) nanofibres for rapid detection of DNA oxidative damage induced by hollow TiO nanocubes. *Electrochem. Commun.* 2009, 11, 783-786. [CrossRef]

- [29] Ensafi, A.A.; Khoddami, E.; Rezaei, B. Aptamer@Au-o-phenylenediamine modified pencil graphite electrode: A new selective electrochemical impedance biosensor for the determination of insulin. *Colloids Surf. B* 2017, 159, 47–53. [CrossRef] [PubMed]
- [30] Zhang, N.; Zhang, K.; Zhang, L.; Wang, H.; Shi, H.; Wang, C. A label-free electrochemical DNA sensor based on ZrO/poly(thionine)/CNT modified electrode and its application for detecting CaMV35S transgene gene sequence. *Anal. Methods* 2015, 7, 3164–3168. [CrossRef]
- [31] Zhang, K.; Zhang, Y. Label-free electrochemical DNA sensor based on gold nanoparticles/poly(neutral red) modified electrode. *Electroanalysis* 2010, 22, 673–679. [CrossRef]
- [32] Kuzin, Y.; Porfireva, A.; Stepanova, V.; Evtugyn, V.; Stoikov, I.; Evtugyn, G.; Hianik, T. Impedimetric detection of DNA damage with the sensor based on silver nanoparticles and neutral red. *Electroanalysis* 2015, 27, 2800–2808. [CrossRef]
- [33] Beiranvand, S.; Azadbakht, A. Electrochemical switching with a DNA aptamer-based electrochemical sensor. *Mater. Sci. Eng.* 2017, 76, 925–933. [CrossRef] [PubMed]
- [34] Wu, L.; Xiao, X.; Chen, K.; Yin, W.; Li, Q.; Wang, P.; Lu, Z.; Ma, J.; Han, H. Ultrasensitive SERS detection of bacillus thuringiensis special gene based on Au@Ag NRs and magnetic beads. *Biosens. Bioelectron.* 2017, 92, 321–327. [CrossRef] [PubMed]
- [35] Stepanova, V.B.; Shurpik, D.N.; Evtugyn, V.G.; Stoikov, I.I.; Evtugyn, G.A.; Osin, Y.N.; Hianik, T. Electrochemical behavior of pillar[5]arene on glassy carbon electrode and its interaction with Cu and Ag ions. *Electrochim. Acta* 2014, 147, 726–734. [CrossRef]
- [36] Smolko, V.; Shurpik, D.; Porfireva, A.; Evtugyn, G.; Stoikov, I.; Hianik, T. Electrochemical aptasensor based on poly(neutral red) and carboxylated pillar[5]arene for sensitive determination of aflatoxin M1. *Electroanalysis* 2018, 30, 486–496. [CrossRef]
- [37] Smolko, V.; Shurpik, D.; Evtugyn, V.; Stoikov, I.; Evtugyn, G. Organic acid and DNA sensing with electrochemical sensor based on carbon black and pillar[5]arene. *Electroanalysis* 2016, 28, 1391–1400. [CrossRef]
- [38] Ogoshi, T.; Aoki, T.; Kitajima, K.; Fujinami, S.; Yamagishi, T.-A.; Nakamoto, Y. Facile, rapid, and high-yield synthesis of pillar[5]arene from commercially available reagents and its X-ray crystal structure. *J. Org. Chem.* 2011, 76, 328–331. [CrossRef] [PubMed]
- [39] Marx, K.A. The quartz crystal microbalance and the electrochemical QCM: Applications to studies of thin polymer films, electron transfer systems, biological macromolecules, biosensors, and cells. *Chem. Sens. Biosens.* 2007, 5, 371–424. [CrossRef]
- [40] Pauliukaite, R.; Brett, C.M.A. Poly(neutral red): Electrosynthesis, characterization, and application as a redox mediator. *Electroanalysis* 2008, 20, 1275–1285. [CrossRef]
- [41] Barsan, M.M.; Pinto, E.M.; Brett, C.M.A. Electrosynthesis and electrochemical characterisation of phenazine polymers for application in biosensors. *Electrochim. Acta* 2008, 53, 3973–3982. [CrossRef]
- [42] Chaubey, A.; Malhotra, B.D. Mediated biosensors. *Biosens. Bioelectron.* 2002, 17, 441–456. [CrossRef]
- [43] Fojta, M.; Daňhel, A.; Havran, L.; Vyskočil, V. Recent progress in electrochemical sensors and assays for DNA damage and repair. *TrAC-Trends Anal. Chem.* 2016, 79, 160–167. [CrossRef]
- [44] Stoewe, R.; Prütz, W.A. Copper-catalyzed DNA damage by ascorbate and hydrogen peroxide: Kinetics and yield. *Free Radic. Biol. Med.* 1987, 3, 97–105. [CrossRef]